Propulsion System Icing

Philip Chow
Honeywell Engines & Systems
May 25, 2006

Topics

- Certification Requirements
- Atmospheric threats
- Engine response in icing
- Engine icing analyses
- Engine icing tests
- References & Guidance

Certification Requirements

Engine operation in icing:

- Part 33.68 Induction System Icing
  - (a) covers in-flight operation
  - (b) covers ground idle operation
- Part 33.77 Foreign Object Ingestion – Ice
  - (c) covers unacceptable engine operation
  - (d) covers special case of engine with inlet protection
  - (e) covers specific ice slab release/ingestion condition
- Advisory Material:
  - AC 20-147

Certification Requirements (Cont.)

Powerplant Icing:

- Part 23.1093, 25.1093, 27.1093, 29.1093

  Induction System Icing Protection

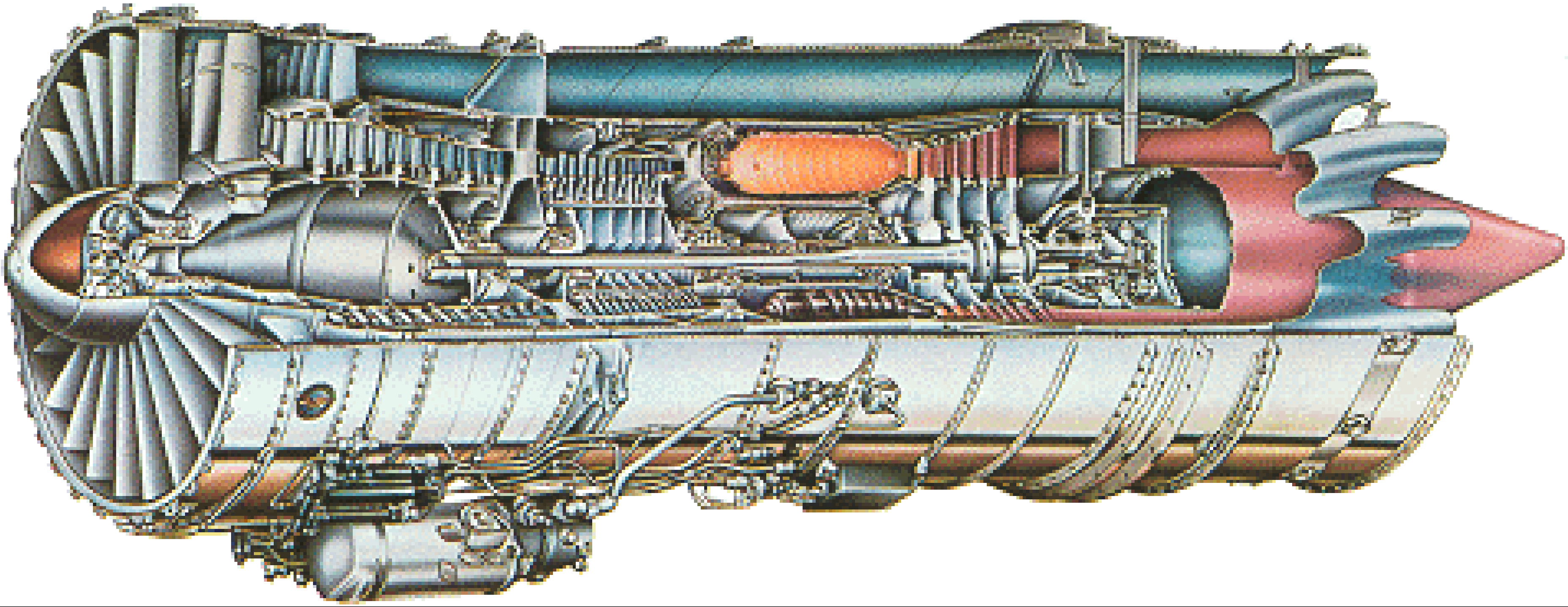
  - (a) covers reciprocating engines (differences between the Part 23, 25, 27 & 29)
  - (b) covers turbine engines (identical in all Parts) – similar to Part 33.68 with the addition of inlet system ice ingestion and falling & blowing snow requirements
  - (c) covers supercharged reciprocating engines (identical reference to (a))
- Advisory Materials:
  - AC 20-73
  - AC 20-147
  - AC 29-2C

Atmospheric Threats

- Supercooled clouds
  - Depicted in Part 25 Appendix C
  - Stratiform clouds represented by Continuous Maximum Icing envelope in the Appendix
  - Cumuliform clouds represented by Intermittent Maximum Icing envelope in the Appendix
- Supercooled (freezing) fog
  - Condition cited in Part (b) of Part 33 induction system icing
- Supercooled Large Droplet (SLD)
  - Depicted in the proposed Part 25 Appendix X
  - Freezing rain droplet size >1000 microns
  - Freezing drizzle droplet size 200-500 microns
- Mixed Phase Icing & Glaciated Ice Crystals
  - A weather threat on propulsion engine operation
  - High ice crystal concentration near thunderstorm or convective cloud structures
  - Maximum altitude exceeds supercooled cloud limits
- Snow

Engine adverse response in icing

- Serious loss of power or thrust during icing exposure
- Loss of engine controllability (unable to accelerate or decelerate)
- Sustained power or thrust loss
- Engine shutdown



Icing scenario that causes serious loss of power or thrust during icing exposure

- Ice blockage on fan or inlet rotating stages
- Bypass passage ice blockage
- Core passage ice blockage (rollback)
- Inlet plenum/inlet screen ice blockage (turboprop, turboshaft)
- Engine sensor probe icing (e.g. P2, T2, PT25)
- Sustained rotating fan stall from fan blade/vane ice build-up

Icing scenario that causes the loss of engine controllability (unable to accelerate or decelerate)

- Ice blockage in the booster stage or engine core section
- Probe icing
- Extremely slow acceleration (e.g. 30 seconds) due to flow blockage and increased rotor inertia from ice buildup at low N1

Icing scenario that causes engine shutdown

- Ice ingestion into combustor causing flameout or surge
- Fan flutter induced by flow field disturbance caused by ice accretion
- Core surge due to ice blockage, probe icing, asymmetric temperature profile after ice shed, or loss of stall margin from rebalanced core
- Severe vibration or vibration induced damage

Icing scenario that causes sustained power or thrust loss

– Ice damage on engine components like fan blade , rub strip (abradable), acoustic panel , fan exit guide vanes, booster or axial compressor blades
– Ice shed, secondary hard-body damage to core compressor hardware

Analyses performed for engine/powerplant icing certification

- Certification critical point analysis
- Engine & inlet components heat transfer analysis
- Ice accretion analysis
- Icing particle trajectory analysis

Critical point analysis performed for the compliance of Part 33.68 icing certification

- Identify the critical operating points in icing within the declared operating envelope of the engine
- Includes a range of possible combinations of icing condition related to the icing envelope, engine speed and power, prolonged operation in icing (in-flight hold) and multiple icing encounters
- Should consider critical ice accretion conditions (cold temperature rime ice & near freezing temperature glaze ice), critical engine operating environment for ice blockage and shedding and critical icing locations
- Use ice accretion analysis and heat transfer analysis to identify the combinations of ambient atmospheric condition and engine operating condition to define the critical icing points
- May include conditions outside the specified icing envelope based on manufacturer best practice

Heat transfer analysis performed on engine & nacelle inlet components

- Heat balance study performed on engine and inlet components to analyze the icing characteristics on the component
- Heat transfer analysis should include convection heating, impingement heating, water sensible heating, phase change latent heats and conduction heating
- Ice accretion analysis is a special heat transfer analysis used to predicts icing characteristics
- Ice protection design requires heat transfer analysis to define energy requirement
- Heat transfer analysis is being studied in FAA/Industry working group to investigate core ice accretion due to mixed phase/glaciated ice crystal ingestion

Ice accretion analysis predicts engine icing characteristics

- Heat balance analysis on critical engine component surfaces where icing particles impinge and accrete
- Includes ambient icing conditions, critical surface water catch efficiency, water impingement rate, forward aircraft flight speed, engine configuration and altitude effect
- Energy balance is performed to determine the freezing fraction of ice accreting on the surface and the rate of accretion
- Ice size can be computed by determining exposure time deduced by combining icing cloud extents and flight speed

Use of icing particle trajectory analysis

- Tracks the trajectory of icing particle released upstream of the engine inlet
- Predicts water impingement zone
- Water catch efficiency can be deduced from this analysis
- 2D analysis may be used in nacelle inlet application
- 3D analysis is required for engine component

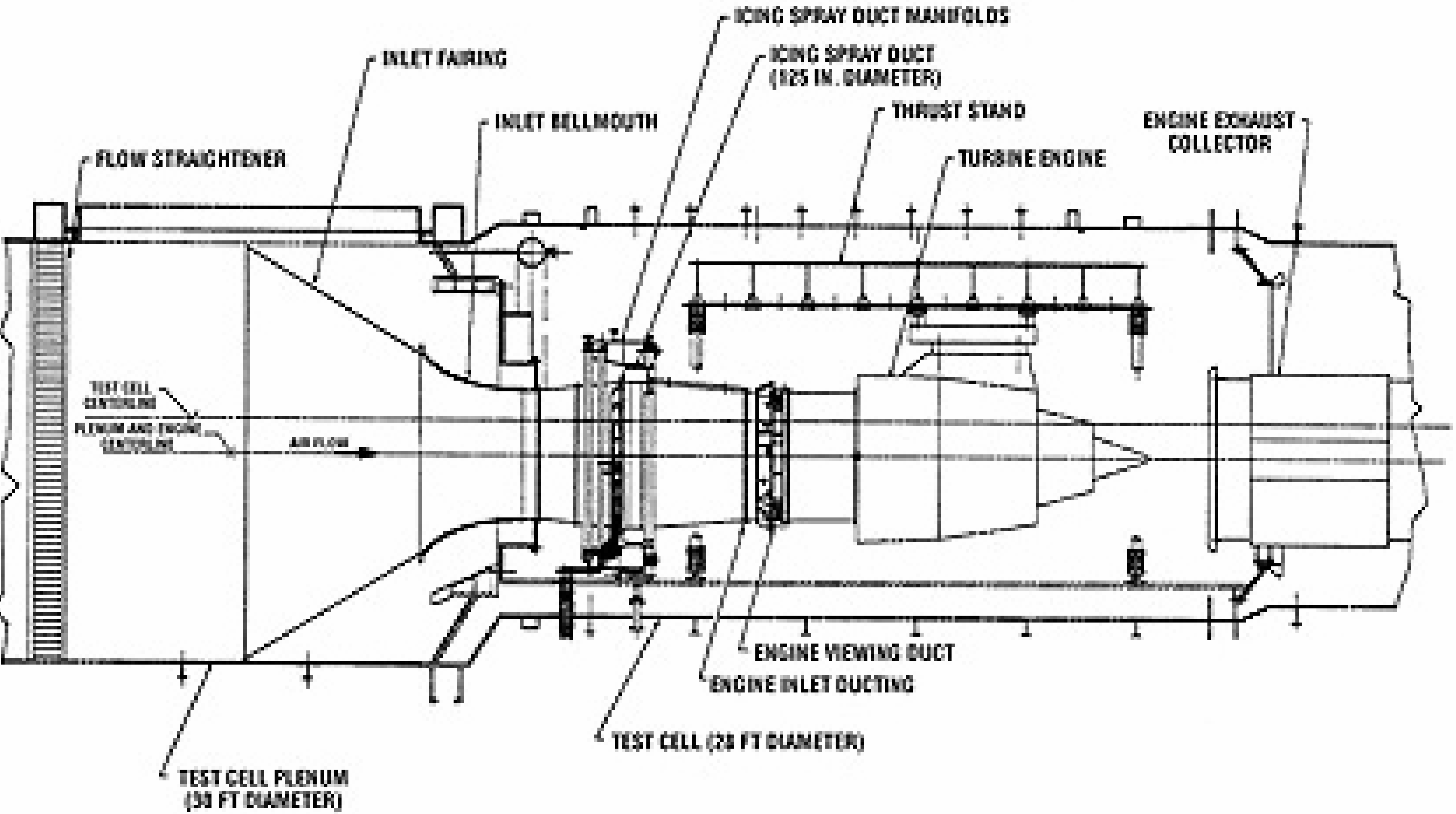
Engine icing tests

- Icing test in altitude test facility
- Icing test in ground level test facility
- Natural icing flight test
- Icing tanker flight test

Engine icing test in altitude test facility

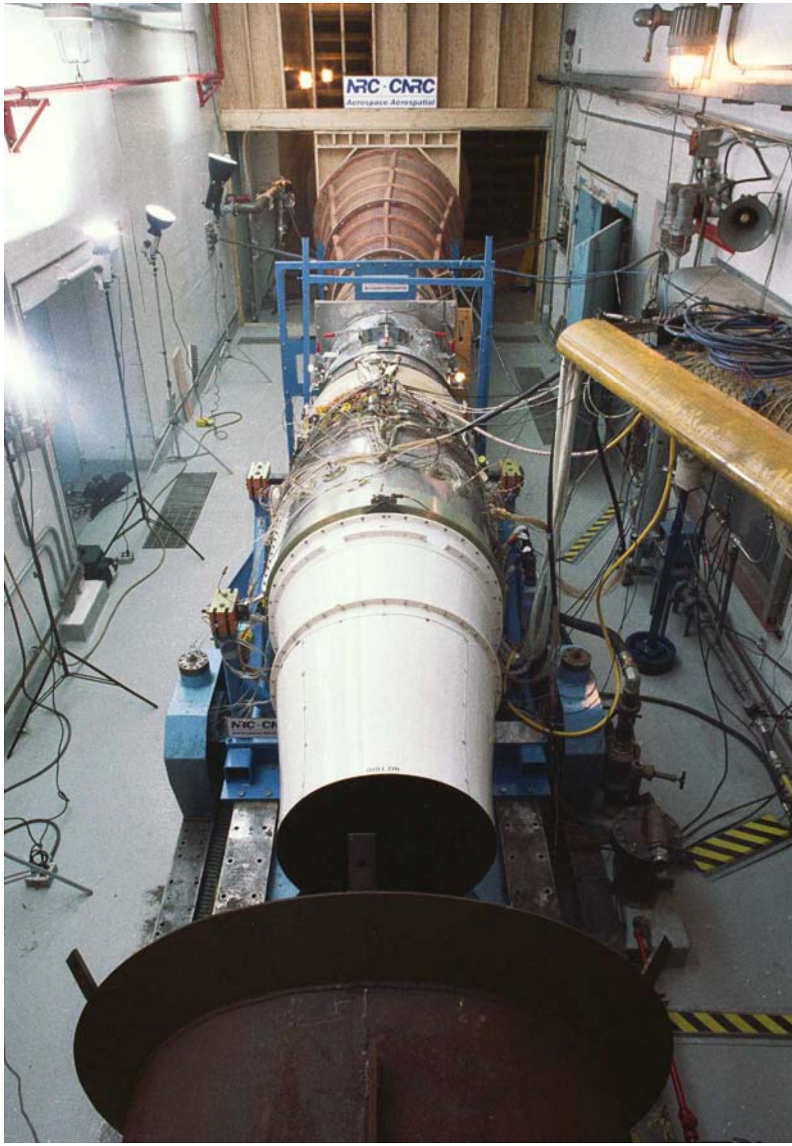
- Full up engine test in simulated altitude and air speed conditions
- More accurate means of testing engine operation in icing because many of the adverse effects are altitude dependent
- Requires special altitude facility with limited access
- Cost of test is generally much higher than sea level facility

AEDC ASTF C-2 ICING FACILITY



Engine icing test in sea level facility

- Most common method used in Part 33 certification
- Ice accretion analysis should be performed to define equivalent ground test points simulating the critical icing points
- Engine operability analysis should be performed to ensure altitude effect is adequately simulated
- Two types of facilities available: open air system & refrigerated air system
  - Open air system depends on the ambient to supply majority of the cold air used in the test, therefore, schedule is control by nature
  - Refrigerated air system uses mechanical means to cool down the test section, generally more expensive to operate


NRC · CNRC

N700JJ

Natural icing flight test

- Commonly used in Part 25 & Part 29 certification
- Testing in the real environment
- Requires a test vehicle that can fly safely in this environment
- Test conditions (e.g. LWC, droplet size) hard to control and most likely not steady during the test
- Icing encounters are scaled to critical points in the icing envelope to demonstrate compliance

Icing test using flying tanker to generate the icing conditions

- Has been used in both Part 25, 29 and Part 33 certifications
- Tested aircraft/powerplant is flown behind a flying tanker which uses a spray rake to generate the simulated icing cloud
- Engine altitude effect is included
- Test conditions are generally controllable
- Cloud uniformity has been a concern
- Reduces risk since not entire airplane is exposed
- Limited cloud size
- Limited tanker access


BRITISH AIRWAYS

Reference & Guidance Materials

- AC 20-73 Aircraft Ice Protection
  - Issued April/71
  - Applies to Part 23.1093(b), Part 25.1093(b), Part 27.1093(b), Part 29.1093(b), etc.
- AC 20-147 Turbojet, Turboprop, and Turbofan Engine Induction System Icing and Ice Ingestion
  - Issued Feb/04
  - Applies to Part 23.1093, Part 25.1093, Part 33.68 & Part 33.77
  - Not intended to address turboshaft installation or rotary wing aircraft icing
- AC 29-2C Certification of Transport Category Rotorcraft
  - Subpart E Paragraph 29.1093 addresses induction system icing protection compliance requirements
  - Paragraph 29.877 describes a special icing certification for rotorcraft that operates under 10,000 feet altitude
- DOT/FAA/CT-88/8-1 Aircraft Icing Handbook
  - Combined 2 earlier reports, "Engineering Summary of Airframe Icing Technical Data" FAA Report ADS-4 and "Engineering Summary of Powerplant Icing Technical Data" FAA Report RD-77-76
  - Comprehensive reference of airframe and engine icing in general